Steel Sandwich Panel Construction

APRIL 2012

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CHANGES

General
This is a new document.
# CONTENTS

1. **Introduction** .................................................................................................................. 5  
   1.1 General ....................................................................................................................... 5  
   1.2 Definitions and terms ............................................................................................... 5  
   1.3 Arrangement ............................................................................................................. 6  
   1.4 Structural principles ............................................................................................... 7  
   1.5 Documentation ......................................................................................................... 9  

2. **Materials and Manufacturing** .......................................................................................... 10  
   2.1 General .................................................................................................................... 10  
   2.2 Face plates and perimeters bars ............................................................................. 10  
   2.3 Core ....................................................................................................................... 11  
   2.4 Manufacture of new panels .................................................................................... 13  
   2.5 Manufacture of overlay panels .............................................................................. 15  
   2.6 Welding .................................................................................................................. 16  
   2.7 Quality assurance and quality control .................................................................... 17  

3. **Strength - New Construction** .......................................................................................... 18  
   3.1 General .................................................................................................................... 18  
   3.2 Thickness allowance .............................................................................................. 19  
   3.3 Primary structure .................................................................................................... 20  
   3.4 Buckling ................................................................................................................ 20  
   3.5 Lateral pressure ...................................................................................................... 24  

4. **Strength Overlay Construction** .................................................................................... 28  
   4.1 General .................................................................................................................... 28  
   4.2 Scantlings ................................................................................................................ 29  

5. **Connections** .................................................................................................................... 29  
   5.1 General .................................................................................................................... 29  
   5.2 Newbuilding ........................................................................................................... 30  
   5.3 Overlay .................................................................................................................. 31  

6. **Fire Safety** ......................................................................................................................... 32  
   6.1 General .................................................................................................................... 32  
   6.2 Newbuilding ........................................................................................................... 32  
   6.3 Overlay .................................................................................................................. 32  

7. **Direct Strength Calculations** .......................................................................................... 33  
   7.1 Introduction .............................................................................................................. 33  
   7.2 Modelling .............................................................................................................. 33  
   7.3 References ............................................................................................................. 34  

Appendix A.  
Symbols and Notations ......................................................................................................... 35  

Appendix B.  
SSPC Strength Calculator ...................................................................................................... 41
1. Introduction

1.1 General

1.1.1 Scope

1.1.1.1 This Classification Note specifies requirements and recommendations for steel sandwich panel construction.

1.1.1.2 The requirements and recommendations apply to both new sandwich construction and overlay sandwich construction used for repair of damaged plated structure.

1.1.1.3 These requirements shall be regarded as supplementary to those given in the DNV Rules for Classification of Ships (hereafter the Rules).

1.1.2 Application

1.1.2.1 The requirements are in general applicable to ship structures constructed in whole or partly using steel sandwich panel construction.

1.1.2.2 Novel applications of steel sandwich panel construction will be specially considered.

Note: Novel applications are defined as proven applications of steel sandwich panel construction in a new environment or an unproven application of steel sandwich panel construction in a known environment.

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1.1.3 Equivalence and future developments

1.1.3.1 Alternative construction of steel sandwich panels or novel applications of these that deviate from the requirements in this Classification Note may be accepted, provided that it is documented by a sound engineering analysis that the level of safety and reliability is at least as high as that given by the requirements of this Classification Note.

1.1.3.2 The requirements set out herein reflect cost-effective means of managing risk at the time of issue. Technology development after that point of time may provide new means of risk reduction.

1.1.4 Materials

1.1.4.1 It is assumed in this Classification Note that the top and bottom plating of the sandwich panel construction is steel or aluminium and of quality in compliance with the Rules, and that the core material of the sandwich panel construction is elastomer and of quality in compliance with the DNV Standard for Certification No. 2.9, Type Approval Programme No. 1-501.20 Elastomer Core Materials for Use in Sandwich Plate Systems (SPS) or Similar.

Note: In this Classification Note the term sandwich panel construction or steel elastomer sandwich panel construction defines a generic type of panels whereas the term Sandwich Plate Systems (or SPS) refers to a specific, patented type of steel elastomer sandwich panel construction.

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1.1.5 Design loads

1.1.5.1 The design loads shall be in accordance with the principles as given in the Rules.

1.2 Definitions and terms

1.2.1 Definitions and descriptions

1.2.1.1 The terms used in this Classification Note have the meanings defined in the following definitions.

1.2.1.2 Steel sandwich panel construction or steel elastomer sandwich panel construction is defined as a structural element consisting of three components: steel plating on each side of a lower density elastomer core. It is assumed that the properties and the proportions of the component materials are such that when a sandwich panel is exposed to a lateral load the bending moments are carried by the steel plating and the shear forces by the core. A schematic of a steel sandwich panel is presented in Fig. 1-1.

1.2.1.3 Overlay or overlay construction is defined as a steel sandwich panel construction used for repair of
damaged plated structure, and where the original damaged plated structure is used as a steel plating on one side of a lower density elastomer core (see Fig. 1-3). The damaged plated structure is typically stiffened by means of secondary supporting members, e.g. stiffeners.

1.2.1.4 Primary members are hull structure members supporting the steel sandwich panel. These are typically:

— deck structure: deck transverse and longitudinal girders
— side structure: side transverse web frames and stringers
— bulkheads: vertical webs and bulkhead stringers
— single and double bottom structure: floors and girders.

1.2.1.5 Bottom plate: the steel plating attached structurally to the primary members.

1.2.1.6 Cavity: the space enclosed between the top and bottom plates and the perimeter bars.

1.2.1.7 Core: a solid material that is continuously bonded to the entire interior surfaces of the steel face plate. The core provides stability to prevent local buckling and sufficient shear capacity to allow the face plates to reach yield under any load condition.

1.2.1.8 Panel: the steel elastomer sandwich panel bounded by primary members.

1.2.1.9 Perimeter bar: the steel flat bars equal to the core thickness, attached typically by welding to the new steel bottom plate or existing plating and used to outline the injection cavity. These are typically placed directly above supporting structure. Other attachment methods, e.g. use of adhesives in low/no heat conditions, will be specially considered.

1.2.1.10 Spacer: rectangular block or disk with a thickness equal to the core thickness and made of the same material. The spacer is secured to the bottom plate and used to ensure adequate spacing between the top and bottom plates during injection.

1.2.1.11 Top plate: in general the steel plating exposed to sea, weather or cargo.

1.2.1.12 Temperature control pressure relief valve: is fitted into sandwich panels that are required to act as a fire boundary. The valves are sacrificial and are only activated under fire load conditions. The size, number and location are to be such that they do not compromise the structural capability of the sandwich construction.

1.3 Arrangement

1.3.1 Basic arrangements

1.3.1.1 The basic structural arrangement for new construction is shown in Fig. 1-2. A typical configuration includes the following components:

— steel top plate
— steel bottom plate
— elastomer core, bonded structurally to the steel plates and perimeter bars
— primary members supporting the panels
— perimeter bars
— temperature control pressure relief valves.

1.3.1.2 The basic structural arrangement for overlay construction is shown in Fig. 1-3. A typical configuration includes the following components:

— new steel top plate
— existing steel bottom plate including primary and/or secondary members supporting the plate
— elastomer core, bonded structurally to the steel plates and perimeter bars
— perimeter bars
— temperature control pressure relief valves.

1.3.1.3 Ranges of thickness are typically from 3 to 30 mm for the steel plates and from 15 to 100 mm for the elastomer core.
1.4 Structural principles

1.4.1 General

1.4.1.1 The assessment for new construction should in general be based on the assumption that the steel sandwich panel replaces the plating and lowest level of stiffeners in a conventional design.

1.4.1.2 When subjected to lateral load the bending moments are carried by the steel plating and the shear forces by the core.

1.4.1.3 The panels (i.e. plating, core and bond) are to have sufficient strength, good damage tolerance and resistance to propagation of fracture in governing load cases.

1.4.1.4 The panel shall be designed such that the loads are introduced through the steel plates.
1.4.1.5 The panels are supported by the primary members and form the flange of the primary members.

1.4.1.6 The design of the panel is to be based on mechanical properties of the elastomer and bond that are representative for this elastomer, production method(s), workshops conditions used, and for the material quality expected over time for the service temperatures selected. This shall be verified by production testing during manufacturing in accordance with Sec.2.

1.4.1.7 The elastomer core material that is used in certain type of steel sandwich panels (e.g. the Sandwich Plate System, or SPS) has been specifically chosen so as to avoid the occurrence of wrinkling (i.e. local buckling) of the face plates.

1.4.1.8 The size and distribution of the temperature control pressure relief valves shall be such that the structural capacity of the panel is not compromised.

1.4.1.9 Local details such as inserts, foundations, base plates etc. are not specifically addressed in this Classification Note. The acceptance of such items will be based on a case-by-case evaluation, including consideration of experience, good practice and direct calculations.

![Figure 1-3](image)

**Figure 1-3**
**Schematic of a typical overlay construction**

1.4.2 Scantlings

1.4.2.1 The scantling derivation for both new sandwich construction and overlay sandwich construction is based on strength equivalence to conventional stiffened panel construction.

1.4.2.2 Allowable design stress and safety factors are predominantly based on the Rules.

1.4.2.3 The strength values and safety factors used in these Classification Notes are based on the following:  
*For steel plates*: Yield strength. Specified value given in Pt.2 Ch.2 Sec.1 of the Rules.  
*For core materials*: Yield strength. Specified minimum value to be taken from DNV Type Approval
Certificate. The specified minimum value is defined as “Mean value - 2 standard deviations” as determined from testing.

Bond strength: Ultimate strength. Specified minimum value defined with a confidence limit of 95% and as determined from testing for varying surface preparation, temperature and stress state.

1.4.2.4 The scantling derivation uses a net scantling approach where the sandwich construction layer thicknesses are those required to be maintained from the newbuilding stage throughout the ship’s design life to satisfy the structural strength requirements.

Note:
For the original plate (in overlay construction) percentage values are applied according to ships in operation approach.

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1.4.2.5 The required gross thickness of the top and bottom face plates, \( t_1 \) and \( t_2 \) respectively, are obtained by adding the appropriate corrosion allowances, \( t_k \), to the required net thicknesses.

1.4.2.6 The required gross thickness of the top and bottom face plates is to be determined by rounding the calculated gross thickness to the nearest half millimetre.

1.4.2.7 The gross thickness is the actual thickness selected by the designer to fulfil the gross required thickness and is to be equal or greater than the required gross thickness before rounding.

1.4.2.8 The as-built thickness is equal to the gross thickness plus the owner/builder specified allowance.

Note:
The total thickness allowances may consist of a corrosion allowance plus an abrasion or wear allowance for example.

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1.4.2.9 An owner/builder specified allowance is an extra margin and is not to be included in the assessment of the required gross thickness.

1.5 Documentation

1.5.1 General

1.5.1.1 Requirements for documentation are to be in compliance with the Rules.

1.5.1.2 Additional documentation not covered by the Rules are herein specified.

1.5.1.3 Where subcontractors and suppliers are involved, the customer shall co-ordinate the submission of required plans and documents, as well as co-ordinate any approval comments given by the Classification Society (hereafter the Society).

1.5.2 Newbuilding

1.5.2.1 The following plans and information shall be submitted for approval:

- drawings showing the sandwich panels specifications i.e. thickness of top and bottom plates, thickness of core materials, tolerances and allowance for corrosion margin and owner’s extra allowance
- extent and location of sandwich construction
- arrangement of cavity i.e. sandwich panel layout
- location and arrangement of spacers
- temperature control pressure relief valve details including size, number and location
- details of integration between sandwich panels and between sandwich panels and conventional steel structure, including scantlings
- details of integration of sandwich panels with primary members, bulkheads, deck, including scantlings
- arrangement of equipment, supports, foundations, etc. in conjunction with their weight and working load information
- construction procedure report
- Quality Assurance (QA) and Quality Control (QC) documentation.

1.5.3 Overlay

1.5.3.1 In addition to the documentation specified above the following plans and information shall be submitted for overlay construction:

- a description of the design objectives (e.g. repair, renewal or reinforcement) including details of the vessels
— an assessment of the condition of the existing structure, including details of the as-built scantlings and a description of the current condition (thickness gauging etc.)
— an assessment of the strength of the altered structure both before and after the application of the sandwich overlay when deemed necessary by the Society
— plans of modifications to the previously approved plans and existing structure if relevant.

1.5.4 Construction procedure

1.5.4.1 The documentation of the construction procedure shall be submitted for approval. The report shall include the following information:

— preparation of existing and new steel
— surface roughness
— preparation of perimeter and cavity
— positioning of restraint system
— pre-injection inspection
— injection process
— removal of restraint and finishing
— post-injection inspection
— welding procedures
— repair and modification procedures.

1.5.5 Direct calculations

1.5.5.1 When direct strength analyses are submitted for information, such analyses shall be supported by documentation satisfactory for verifying results obtained from the analyses.

1.5.5.2 General requirements for documentation are given in Pt.3 Ch.1 Sec.12 A300 of the Rules.

1.5.6 Certificates

1.5.6.1 Rolled steel, aluminium and elastomer materials are normally to be supplied with DNV's certificates in compliance with the requirements given in the Rules.

2. Materials and Manufacturing

2.1 General

2.1.1 General requirements

2.1.1.1 This section specifies requirements for materials, manufacture, survey and certification of steel sandwich panels used in the construction or repair of hulls of vessels classed or intended for classification by the Society.

2.1.1.2 The requirements given in this section apply to steel sandwich construction and shall be regarded as supplementary to those given in Pt.2 of the Rules.

2.1.1.3 Close attention shall be given the manufacture procedures at all stages as the final properties of the steel sandwich construction are controlled by the yard or the fabricator, and not the supplier of the raw materials. This is different compared with a normal shipbuilding situation.

2.1.1.4 A good bond is necessary to ensure the sandwich effect and activate the shear load capacity of the core. The bond strength is dependent on the mechanical properties of the elastomer, the workshops conditions experienced and the production method used. The bond strength is particularly important for new sandwich construction where no secondary stiffeners are used to transfer the loads to the primary members.

2.1.1.5 The electrical continuity of all metal structures including steel sandwich construction shall be ensured in order to minimise risk of electric shock.

2.2 Face plates and perimeters bars

2.2.1 General

2.2.1.1 In this section requirements related to steel components used for steel sandwich construction classed or intended for classification with the Society are given.

2.2.1.2 Top and bottom plating: Rolled steel for top and bottom plating of steel sandwich construction is
normally to be supplied with a Society’s material certificate in compliance with the requirements given in Pt.2 Ch.2 of the Rules.

2.2.1.3 For overlay construction top plates should generally be made of the same grade as existing structure or higher grade when required for improved strength.

2.2.1.4 Perimeter bars: See requirement above.

2.3 Core

2.3.1 Scope

2.3.1.1 The requirements in this section apply to in situ elastomer core materials used for steel sandwich construction classed or intended for classification with the Society.

2.3.1.2 Other core materials than elastomer cores may be accepted based upon testing and approval in each individual case.

2.3.2 Type Approval

2.3.2.1 The approval procedures for the elastomer core materials covered in this section are specified in the DNV Type Approval Programme for elastomer core materials.

2.3.2.2 The approval will be related to a set of physical properties, which will be stated in the DNV Type Approval Certificate. The minimum properties are to be specified by the manufacturer and verified by the approval testing.

2.3.3 Certificate

2.3.3.1 Core materials of steel sandwich construction are normally to be supplied with a DNV Type Approval Certificate.

2.3.4 General requirements

2.3.4.1 Core materials shall have stable long term properties. Continuous chemical processes, diffusion etc. shall not affect the physical properties of the core material or the core-to-plating interface. If considered necessary, documentation of specific long term properties may be required.

2.3.4.2 If special surface treatment is required, this shall be stated in the application for Type Approval, and it will be stated, or referenced, on the DNV Type Approval Certificate.

2.3.5 Properties of components

2.3.5.1 The requirements for the components used in the elastomer core materials for use in Sandwich Plate Systems are stated in Table 2-1. Further details regarding requirements for testing and documentation are stated in the DNV Type Approval Programme for elastomer core materials.

2.3.5.2 Other test methods/test specifications, standardised or internal, may be agreed upon with the Society prior to testing.

2.3.5.3 Components with properties outside of the acceptance criteria in Table 2-1 may be accepted by the Society if it can be demonstrated to the Society’s satisfaction that the resultant elastomer core material meets the requirements of Table 2-1.

2.3.5.4 For other core materials than polyurethane elastomer cores, the extent of the manufacturer’s quality control for the components used before and during production to ensure even product quality shall be agreed with the Society in advance.

| Table 2-1 Manufacturer's quality control for the components used in the elastomer core material |
|-----------------------------------------------|--------------|----------------|-----------------|------------------|
| Property                                    | Test standard | Acceptance criteria | Minimum level of verification | Frequency of control |
| Component A (e.g. Polyol)                    | DIN 53240     | 325 ± 35mg KOH/g    | Results reported on inspection certificate | Each batch          |
| Hydroxyl Number                             | DIN EN ISO 14896 | 31.5 ± 1%       | Results reported on inspection certificate | Each batch          |
| Component B (e.g. Isocyanate)               |               |                  |                               |                   |
| NCO content                                 |               |                  |                               |                   |
2.3.6 Properties of cured elastomer core materials

2.3.6.1 The required properties for the cured elastomer core materials for use in Sandwich Plate Systems are stated in Table 2-2. Further details regarding requirements for testing and documentation are stated in the DNV Type Approval Programme for elastomer core materials. For requirements for production testing, see 2.7.4.

Note:

For the elastomer core material for use in Sandwich Plate System due attention should be given to the reduction of mechanical properties with increasing temperatures.

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2.3.6.2 For other core materials the properties requirements shall be agreed with the Society in advance.

Table 2-2 Requirements to cured elastomer core materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Test standard 1)</th>
<th>Number of parallels</th>
<th>Acceptance criteria</th>
<th>Minimum level of verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ISO 845</td>
<td>min. 5</td>
<td>&gt; 1000 kg/m³</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Hardness</td>
<td>DIN53505</td>
<td>min. 5</td>
<td>65 at 20°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ISO 527</td>
<td>min. 5</td>
<td>&gt; 5 MPa at +80°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>ASTM D412</td>
<td>min. 5</td>
<td>&gt; 200 MPa at +80°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>ISO 604</td>
<td>min. 5</td>
<td>&gt; 5 MPa at +80°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>ASTM D575</td>
<td>min. 5</td>
<td>&gt; 200 MPa at +80°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Compressive Modulus</td>
<td>Torsion Pendulum Test -20°C to +80°C, or +80°C only DIN EN ISO 6721-2</td>
<td>min. 5</td>
<td>G ≥ 312-2.4T (°C) 2) or, min. 120 MPa at +80°C</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Bond shear strength</td>
<td>ASTM D429-81</td>
<td>min. 5</td>
<td>3.7 MPa (shot blasted) 3) 6.2 MPa (grit blasted)</td>
<td>DNV Survey</td>
</tr>
<tr>
<td>Bond shear strength from beam flexure 4)</td>
<td>ASTM C393</td>
<td>min. 5</td>
<td>characteristic value 5) &gt; allowable stress defined in 3.5.2</td>
<td>DNV Survey</td>
</tr>
</tbody>
</table>

1) Other test methods/test specifications, standardised or internal, may be agreed upon with the Society prior to testing.
2) T is the temperature in °C.
3) See Note below.
4) Subject to special consideration in each separate case, see 2.3.6.3.
5) Characteristic value given by the mean – 3 standard deviations.

Note:

For the elastomer core material for use in Sandwich Plate System, the bond shear strength values shown on the DNV Type Approval Certificate (i.e. 2.7 MPa and 4 MPa) correspond to allowable interface shear stress values established for shot blasted surface preparation and grit blasted surface preparation, for room temperature and for the stress state on the bond interface that correspond to that of the ADTM D429-81 test. These values should not be used for design purpose. Instead, the approach presented in 3.5.2 should be used.

The values presented in Table 2-2 are characteristic values given by the mean – 3 standard deviations for shot blasted surface preparation and grit blasted surface preparation, for room temperature and for the stress state on the bond interface that correspond to that of the ADTM D429-81 test.

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2.3.6.3 In certain cases (e.g. novel application) the bond shear strength from beam flexure shall be established. The test specimens shall be representative of the surface preparation(s) and testing shall be carried out at the
relevant temperature(s).

2.3.7 Long term properties of cured elastomer core materials

2.3.7.1 The following long term data shall be established for the cured elastomer core materials and the bond. Standards may be agreed upon with the Society prior to testing. Deviations from some or all of these requirements may be allowed subject to agreement case by case with the Society.

— tensile strength
— tensile modulus
— elongation at break
— shear modulus
— bond shear strength.

Note:
In addition to static properties, properties under constant permanent static loads or deformations, and properties under cyclic loads or deformations should be established. In the long-term properties may be influenced not only by the loads but also by the environment, or by the combination of environment with loads, e.g. creep and stress rupture. Testing should be carried out after being weathered (accelerated or not accelerated) or while weathered according to agreed test standards where the environment should be represented in a realistic manner.

2.4 Manufacture of new panels

2.4.1 General requirements

2.4.1.1 In this Section requirements related to the manufacturing, quality assurance and quality control of steel sandwich panel construction classed or intended for classification with the Society are given.

2.4.2 Storage of raw materials

2.4.2.1 Storage premises are to be so equipped and arranged that the raw material supplier's instructions for storage and handling of the raw materials can be followed.

2.4.3 Manufacturing premises and conditions

2.4.3.1 Manufacturing premises are to be so equipped and arranged that the raw material supplier's instructions for handling the materials and the yard or fabricator's instructions for the injection process and curing conditions can be followed.

2.4.4 Workmanship

2.4.4.1 All workmanship is to be of commercial marine quality, acceptable to the Surveyor and in compliance with the requirements of this section.

2.4.5 Preparation of cavity

2.4.5.1 For Sandwich Plate Systems, the cavity surfaces shall be prepared by mechanical grinding, grit blasting, shot blasting, primer application or other surface preparation method that satisfy the following requirements:

— A cleanliness to Swedish Standard Sa2.5 or The Society for Protective Coatings SSPC-SP 10 (NACE 2) is to be achieved on the bonding surfaces before injection of elastomer. Alternative surface finishes will only be considered on an individual basis and will require validation by an agreed test program.
— The cavity surfaces shall be clean and dry, free from oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint or other foreign matter and grit free prior to injection.
— The potential bond strength for a given surface preparation shall be characterized by conducting 5 PosiTests in accordance with the adhesion test procedure specified in the QA documentation. The test shall be carried out on a sample cured for 24 hours under the same conditions as the elastomer batch injected. The tests shall be carried out in the presence of a Surveyor.
— The steel surface preparation acceptance is based on the test data evaluation described below and criteria given in Table 2-3.
— The mean value, \( \bar{\sigma} \), and standard deviation, \( \mu \), of the nominal normal bond stress \( \sigma_{\text{bond, normal}} = P/A \) where \( P \) is the force which separates the core from the face plate, \( A \) is the cross sectional area of core sample) across the steel-core interface shall be calculated from the test data.
— Outlier data is defined as any result that is less than or greater than \( 3\mu \) from the mean.
— Outliers are to be discarded and further PosiTest samples tested as required.
If $\bar{x} > x_{\text{lim}}$, the surface preparation modification factor, $\phi_s$, for the specified surface preparation is given in Table 3-7; the surface preparation is acceptable. $x_{\text{lim}}$ is given in Table 2-3.

If $\bar{x} < x_{\text{lim}}$, then the surface preparation must be reapplied.

<table>
<thead>
<tr>
<th>Surface preparation</th>
<th>$x_{\text{lim}}$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical grinding</td>
<td>10</td>
</tr>
<tr>
<td>Grit blast</td>
<td>8</td>
</tr>
<tr>
<td>Shot blast</td>
<td>6</td>
</tr>
<tr>
<td>Primer</td>
<td>3</td>
</tr>
</tbody>
</table>

2.4.5.2 For surface preparations not specifically listed, the surface preparation modification factor shall be calculated, by the expression given below.

$$\phi_s = 0.125(\bar{x} - 1.6\mu)$$

2.4.5.3 Small steel defects that may impair the quality of the panel shall be repaired prior to injection.

2.4.5.4 Steel plates and perimeter bars shall not be subjected to avertable distortion and loading during the construction process.

2.4.5.5 Perimeter bars shall be welded to the bottom plate in line with the construction drawings.

2.4.5.6 Spacers made of elastomer (or any other suitable material or method) shall be used to provide the required core thickness during injection. When glued spacers are used the adhesive system used shall be specified in the construction procedure.

2.4.5.7 Panels shall be suitably supported until the elastomer has cured to avoid distortion.

2.4.6 Welding

2.4.6.1 In general all welding shall be in compliance with the requirements set in the Rules.

2.4.6.2 All main structural welds (e.g. lashing points, cavities, pad eyes, foundations etc.) shall be completed before injection.

2.4.6.3 Welding of the cavity being injected or of adjacent cavities shall be completed before injection.

2.4.6.4 Welding shall be performed in accordance with the construction procedure and QA documentation.

2.4.7 Preparation for injection

2.4.7.1 Injection ports and vent holes shall be located in the top plate in accordance with the construction procedure documentation.

2.4.7.2 For Sandwich Plate Systems, the cavity shall be free from moisture before injection. The relative humidity in the cavity shall be measured and recorded in accordance with the construction procedure and QA documentation. The moisture content of the air in the cavity should not be more than 3.0 g per kg air.

2.4.7.3 For Sandwich Plate Systems, the cavity formed by the steel plates and perimeters bars shall be air tight. Air tightness shall be checked, measured and recorded in accordance with the construction procedure and QA documentation. The cavity should be able to withstand minimum pressurisation of 0.1 bar for a period of 1 minute.

2.4.8 Restraint system

2.4.8.1 The positioning of the restraint system shall be arranged in accordance with the construction procedure and QA documentation.

2.4.9 Elastomer and base components

2.4.9.1 For each batch base components and specifications shall be identified prior to injection.

2.4.9.2 For Sandwich Plate Systems, for each batch of elastomer a minimum of 5 Shore D hardness tests shall be carried out on cured elastomer injected on site in accordance with DIN 53505. The Shore D hardness value is defined as the mean value as determined from tests at standard room temperature. The Shore D hardness value shall not be smaller than 65. The test shall be carried out on a sample cured for 24 hours under the same
conditions as the elastomer batch injected. The block of elastomer material should be prepared from an injection bucket shot or the centre of a 40 mm thick elastomer core from machine injection into a large mould. The tests shall be carried out in the presence of a Surveyor.

2.4.9.3 For Sandwich Plate Systems, the pot life shall be determined by a test sample injected on site for each batch of elastomer. The pot life value should normally not exceed 720 seconds. The pot life shall be greater than the time required to fill the cavity. The tests shall be carried out in the presence of a Surveyor unless otherwise agreed.

2.4.10 Injection and curing

2.4.10.1 The pumping, mixing and injection equipment shall be used, calibrated and maintained in accordance with the (equipment) manufacturer’s guidelines. A certificate(s) of calibration shall be included in the QC documentation.

2.4.10.2 Injection shall be carried out once the cavity’s quality is deemed satisfactory for injection.

2.4.10.3 Injection shall be performed in accordance with the construction procedure and QA documentation.

2.4.10.4 After injection, during the curing cycle of the elastomer, an exothermic reaction occurs. This reaction will reach a maximum average temperature through the core. This maximum average temperature is assessed by measuring the temperature reached on the external face of the upper steel plate. This temperature should be measured as close to the middle of the plate as possible. The minimum steel plate temperature required is project dependent, but it is generally 40°C or above.

2.4.11 Post injection inspection

2.4.11.1 After completion of the injection the cured elastomer shall be tested. For every 1000 m² of panel a minimum of two levelling funnels shall be Shore D hardness tested in the presence of a Surveyor unless otherwise agreed. The results shall comply with the criteria given in 2.4.9.2.

2.4.11.2 After curing of the elastomer the injection and venting holes shall be sealed by welding a steel disk in each hole.

2.4.11.3 Where required the holes for the high temperature control valves shall be drilled in accordance with the construction procedure and QA documentation.

2.4.11.4 Defects shall be brought to the attention of the Surveyor.

2.4.11.5 The plate should be checked for voids by any of the following methods:

— tap testing or hammer test
— resonance response detection equipment named SONALIS
— alternative equivalent methods.

2.4.11.6 As a minimum the QA documentation shall define the maximum allowable void size and maximum permissible un-bonded plate area.

2.4.12 Repair

2.4.12.1 Defects larger than the maximum critical size defined in the QA documentation shall be repaired. Repair of defects shall be agreed with the Surveyor prior to being carried out.

2.4.12.2 Repairs shall be performed in accordance with repair procedures specified in the construction procedure and QA documentation.

2.4.12.3 Approved tools and methods for cutting, grinding, welding etc. used for repair of various defects shall be specified in the construction procedure and QA documentation.

2.4.12.4 Welding for repair of defects shall be carried out in accordance with 2.4.6.

2.5 Manufacture of overlay panels

2.5.1 General requirements

2.5.1.1 This sub-section specifies the requirements for the manufacture of sandwich panels by overlay construction.

2.5.1.2 The requirements shall be regarded as supplementary to those given in 2.4.
2.5.2 Minimum thickness of original plate

2.5.2.1 Overlay construction shall only be applied when the average gauged thickness is equal to or greater than 65% of the rule original plate thickness, i.e. when the allowable maximum average plate reduction is 35%. Local areas with higher reductions may be accepted on a case by case evaluation.

2.5.3 Suitability of existing structure

2.5.3.1 The minimum net thickness of the existing plating is 3.0 mm.

2.5.3.2 Stiffeners, beams and girders shall be intact or repaired according to the Rules prior to overlay application.

2.5.3.3 The structural contribution for the existing plating can be considered in the design of overlay construction if it can be demonstrated by direct calculation that the overlay construction satisfies the design requirements, otherwise the damaged stiffeners are to be neglected and the plate designed in accordance with the rules for new construction with the bottom face plate net thickness defined in Sec.4.

2.5.4 Preparation of existing steel surface

2.5.4.1 Perimeter bars shall be welded to the existing bottom plate in line with the construction drawings. Other methods may be accepted on a case by case evaluation.

2.5.4.2 In general the material, manufacture and construction processes for overlay are to follow the requirements of Sec.2.

2.5.5 Overlay cavity layout

2.5.5.1 Cavity layout should use the underlying primary structure to the extent practicable to ensure perimeter bars are attached to structure that is least deformed.

2.5.5.2 Cavity width shall be based on available plate widths and the spacing of underlying stiffening elements.

2.5.5.3 Cavity lengths are based on the pot life of the elastomer, the injection rate and cavity volume.

2.5.5.4 Cavity aspect ratios are typically four or five to one.

2.5.5.5 Cavity volume including additional volume associated with the deformed existing plating between stiffeners is limited to the maximum specified injection capacity of the injection equipment.

2.5.6 Preparation of cavity

2.5.6.1 See 2.4.5.1.

2.5.7 Elastomer and base components

2.5.7.1 For each batch of elastomer a minimum of 5 Shore D hardness test shall be carried out. The tests shall be carried out in the presence of a Surveyor unless otherwise agreed.

2.5.7.2 See 2.4.9.

2.5.8 Post injection inspection

2.5.8.1 The injection and venting holes are typically sealed by welding a steel disk into each hole. For overlay applications in tanks, threaded plugs may be used to seal the injection and vent holes.

2.5.8.2 See 2.4.11.

2.6 Welding

2.6.1 General requirements

2.6.1.1 The requirements given in this section apply to steel sandwich construction and shall be regarded as supplementary to those given in Pt.2 Ch.3 of the Rules.

2.6.1.2 For panels with injected cavities welding to the face plates can be carried out provided that the heat input or residual stresses due to welding (shrinkage) does not affect adversely the load bearing capacity of the panel. Documentation presenting the risk mitigation from heat input shall be submitted in the construction procedure and QA documentation.
2.6.1.3 Welding of minor temporary attachments can be carried out without the use of internal reinforcements.

2.6.1.4 In general, welding to face plates with thicknesses equal to 6 mm or less is not permitted unless heat sink plates are incorporated in the design.

2.6.1.5 The maximum temperature at the interface between the face plate and the elastomer directly opposite of the weld cannot exceed 250°C for any given weld procedure.

2.6.1.6 In general, the maximum permissible fillet weld leg size that satisfies 2.6.1.5 is equal to or less than one half the face plate thickness.

2.6.1.7 Multiple weld passes can be used to create larger welds if 2.6.1.2 and 2.6.1.5 are satisfied.

2.7 Quality assurance and quality control

2.7.1 Quality assurance

2.7.1.1 The yard or the fabricator shall have implemented an efficient system for quality assurance to ensure that the finished product meets the specified requirements. The person or department responsible for the quality assurance shall have clearly established authority and responsibility and be independent of the production departments.

2.7.1.2 The system should be formalized through a quality handbook or similar document at least containing the following main objects:

- organisation of all quality related activities
- identification of key personnel and their responsibilities
- procedures for documentation
- qualification of personnel
- manufacturing conditions including recording of temperature and humidity
- receipt and storage of raw materials
- working procedures and instructions for all steps
- procedures for quality control, inspection and testing (surface preparation, moisture, air tightness, characterisation of elastomer and bond, injection and curing)
- repair procedures
- acceptance criteria for typical defects.

2.7.1.3 The quality handbook or equivalent shall be made available to the Surveyor.

2.7.2 Quality control

2.7.2.1 A written quality control plan shall be established for the production. The quality plan is subject to approval of the Surveyor prior to commencement of the production.

2.7.2.2 The quality control plan shall address at least the following items:

- relevant specifications, rules, statutory requirements etc.
- drawings
- list of raw materials
- procedures for handling of raw materials
- manufacturing procedures and instructions
- procedure for keeping and filing of cavity preparation records (surface preparation, moisture, air tightness)
- procedure for keeping and filing of injection records
- procedure for keeping and filing of cure logs
- procedures for quality control and inspection or testing
- inspection points
- witness points by the DNV Surveyor
- production testing of panels in accordance with paragraph below
- procedures for corrective actions when deficiencies are identified.

2.7.2.3 The quality plan may contain copies of all the necessary documentation or may refer to documents in the quality handbook or other controlled documentation. The relevant drawings may e.g. be identified by a list of drawings.

2.7.3 Production testing

2.7.3.1 The purpose of production testing is to verify that a consistent level of quality is maintained throughout production.
2.7.3.2 The yard or the fabrickator shall specify a production test plan, as part of the quality plan, which as a minimum is to address the following items:

— mechanical strength of major attachments and joints
— elastic properties of the core material
— bond strength between core and face plates
— void test
— the selected acceptance criteria to be used.

2.7.3.3 Production testing (from the production line, storage etc.) shall be witnessed by the Surveyor unless otherwise agreed, see 2.4 and 2.5.

2.7.3.4 The test plan is subject to approval by DNV approval engineer prior to commencement of fabrication.

2.7.3.5 The test results shall be in accordance with the values of mechanical strength used in the design and indicate a level of workmanship in line with good industry standard. The test results shall be submitted to and approved by the responsible approval engineer.

2.7.3.6 Material selection, design, fabrication methods and QA/QC procedures may differ significantly between different vessels and yards or fabricators. A larger or different extent of testing may therefore be required by the Society. The extent of testing may also be made dependent on the degree of utilisation of the particular component or the consequences of a failure of the component.

2.7.4 Production testing of SPS elastomer

2.7.4.1 For the elastomer core material for use in Sandwich Plate System, fabricators, builders or manufacturers of sandwich panels should periodically test cured elastomer to ensure that the material properties listed below satisfy the criteria given in Table 2-2. The schedule of testing is to be determined by the Society but not to be greater than a 12 month interval between test series. The material properties are as follows:

— density
— hardness (Shore D)
— tensile stress
— tensile modulus
— elongation at break
— compressive strength
— compressive modulus
— shear modulus
— bond shear strength.

2.7.4.2 A minimum of 5 test specimens for each test type are to be taken from a block of elastomer material prepared in accordance with 2.4.9.2.

2.7.4.3 Recognised standards to which test specimens are to be tested and acceptance criteria are listed in Table 2-2. The mean value and standard deviation for each test sample and test type are to be calculated. Outliers are to be discarded and replacement test conducted, when an outlier is defined as any result that is less than or greater than 3 standard deviations from the mean. If the mean value is less than the acceptance criteria then the batch of elastomer is to be rejected.

3. Strength - New Construction

3.1 General

3.1.1 Scantlings

3.1.1.1 Scantlings of steel sandwich panels as a part of a hull structure shall satisfy buckling, stress and deflection criteria considering local pressures and in-plane stresses from all relevant hull responses such as global hull girder bending, primary girder/floor bending, double hull bending etc.

3.1.1.2 The assessment of the hull loads follows the Rules while the dimensioning of nominal hull stresses shall consider the actual strength and stiffness of the steel sandwich panels.

3.1.1.3 Scantlings of steel sandwich panels as part of a hatch cover shall satisfy stress, deflection and buckling criteria considering local pressures, local loads etc.

3.1.1.4 The assessment of the hatch cover loads follows the Rules, while the dimensioning stresses shall
consider the actual strength and stiffness of the steel sandwich panels.

3.1.1.5 For special steel sandwich construction the panels shall satisfy buckling, stress and deflection criteria considering all relevant loads and load effects, which are to be determined from direct analyses or equivalent. The assessments of the dimensioning stresses are to be based on Rule loads whenever available. Loads based on direct analyses (e.g. green sea analyses) can be applied based on a case by case approval by the Society.

3.1.1.6 Steel sandwich panels are to be designed according to the following principles:
— to avoid major plastic yielding of steel face plating
— to avoid major plastic yielding of core material
— to avoid failure of the bond between the core and the steel face plates.

3.1.1.7 Buckling and lateral pressure criteria are considered separately according to the following scheme:

**Buckling criteria:** Consider all in-plane stresses from overall primary structural response.

**Local pressures criteria:** Consider local lateral pressure with respect to maximum equivalent bending stress of the steel plates, shear stress in the core and along the interface.

### 3.1.2 Minimum thickness

3.1.2.1 The top and bottom plate thicknesses of the steel sandwich panel shall not be less than

\[ t_{1,2,\text{min}} = 0.5 \left( t_0 + \frac{k \cdot L}{f_{j,0.5}} \right) \]

where \( L \) is the length of the ship and \( f_{j} \) is the DNV material factor depending on material strength group and where \( t_0 \) and \( k \) are parameters given in Table 3-1.

<table>
<thead>
<tr>
<th>Table 3-1 Minimum thickness parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
</tr>
<tr>
<td>Bottom / Inner bottom / Side</td>
</tr>
<tr>
<td>Weather deck</td>
</tr>
<tr>
<td>Bulkhead</td>
</tr>
<tr>
<td>Tween decks &amp; superstructure ends and sides</td>
</tr>
<tr>
<td>Superstructure decks</td>
</tr>
</tbody>
</table>

**Note:** Examples of minimum thickness are given in Table 3-2.

---e-n-d---of---N-o-t-e---

<table>
<thead>
<tr>
<th>Table 3-2 Minimum thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Bottom / Inner bottom / Side</td>
</tr>
<tr>
<td>Weather deck</td>
</tr>
<tr>
<td>Bulkhead</td>
</tr>
<tr>
<td>Tween decks &amp; superstructure ends and sides</td>
</tr>
<tr>
<td>Superstructure decks</td>
</tr>
</tbody>
</table>

### 3.2 Thickness allowance

3.2.1 Requirements

3.2.1.1 The local corrosion allowances, \( t_k \), to be applied to the top and bottom steel plates are given in Table 3-1 and Table 3-2.

3.2.1.2 The gross thickness required \( t_{1,2,\text{gross,required}} \) shall be not less than

\[ t_{1,2,\text{gross,required}} = t_{1,2,\text{net,required}} + t_k \]
3.2.1.3 For double skin hatch covers, where the bottom skin is made of conventional stiffened panels, the corrosion allowances for conventional hatch cover construction given in Pt.3 Ch.3 Sec.6 Table E3 of the Rules shall be used.

### Table 3-3 Corrosion allowance, \( t_k \), in mm

<table>
<thead>
<tr>
<th>Structural member</th>
<th>Exposure Type, upper or lower plate of the sandwich, whichever is relevant</th>
<th>Corrosion addition Bulk Carriers and Dry Cargo Vessels</th>
<th>Corrosion addition Tankers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper deck panel (weather deck)</td>
<td>Atmosphere</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Cargo hold / cargo tank</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Ballast tank</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Inner bottom and hopper tank panel in cargo area</td>
<td>Cargo hold / cargo tank</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Ballast tank</td>
<td>1.5</td>
<td>1.0 / 1.5 (1)</td>
</tr>
<tr>
<td></td>
<td>Fuel tank</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Void space</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Inner bottom outside cargo area</td>
<td>Engine room/steering gear room etc.</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Fuel/lub. oil/fresh water/void space</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Internal car decks and ramps</td>
<td>Upper plate in sandwich</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Lower plate in sandwich</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Other panels</td>
<td>case by case</td>
<td>case by case</td>
<td></td>
</tr>
</tbody>
</table>

(1) When heated cargo tank

### Table 3-4 Corrosion allowance for weather deck hatch covers of cargo holds

<table>
<thead>
<tr>
<th>Application</th>
<th>Hatch cover configuration</th>
<th>( t_k ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk carriers, ore carriers and combination carriers</td>
<td>Weather face</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Cargo</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Internal space</td>
<td>0.5</td>
</tr>
<tr>
<td>Cellular cargo holds intended for containers</td>
<td>Weather face or cargo</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Internal space</td>
<td>0.5</td>
</tr>
<tr>
<td>All other ship types</td>
<td>Weather face or cargo</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Internal space</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The corrosion allowance is 0 mm for the core face

### 3.3 Primary structure

#### 3.3.1 Requirements

3.3.1.1 The requirements of primary support members are given in the appropriate chapters of the Rules.

#### 3.3.2 Effective flange

3.3.2.1 Both the top and bottom face plates of sandwich plate construction are considered to form an effective flange for primary steel support members. For cases when only one of the plates is directly connected to the support member, the contribution from the other plate shall be documented if required and in agreement with the Society.

#### 3.3.3 Core material stiffness parameters

3.3.3.1 In lack of accurate material stiffness data the following values can be used in buckling and lateral load strength assessments:

\[
G_c = 297 \text{ MPa} \\
E_c = 748 \text{ MPa} \\
\nu_c = 0.26
\]

These values can be used as long as the temperature is less than 40°C. For higher temperatures an agreement with the Society on case-by-case is needed for defining acceptable values.

### 3.4 Buckling

#### 3.4.1 Criteria

3.4.1.1 The present buckling criteria consider elastic buckling and material yielding in interaction.
The buckling failure mode consider overall deflections of the steel sandwich panel as an integrated unit assuming the bonding between the steel face plates and core polymer to be intact. Failure of the core or bonding to steel face plates will not take place for loads/stresses satisfying the present buckling criteria.

3.4.1.2 Wrinkling buckling of the individual steel face plates is not considered to be a relevant failure mode for steel sandwich panels of normal design.

3.4.1.3 The design loads/stresses \( N_{10}, N_{20}, N_{30} \) taken from hull Rules are normally representative for an environmental design lifetime level of twenty years \( (10^{-8}) \) or more (e.g. Pt.3, Ch.1 Sec.13; \( \sigma_{ax}, \sigma_{ay}, \tau_{a} \)).

![Figure 3-1](image)

*Figure 3-1 Schematic illustration of SPS plate layout and load directions*

3.4.1.4 The dimensioning buckling stresses are generally to be based on extreme loads relevant for the design lifetime loads \( (10^{-8}) \).

If the design stresses are taken at \( 10^{-4} \) level, the acceptable design limit is set to be 20% less than for extreme design lifetime loads \( (10^{-8}) \).

For redundant structures for which the consequence of failure of the sandwich panel is small the following allowable usage factors apply:

- Wave load at \( 10^{-8} \) level, 20 year design conditions \( \eta_{allow} = 0.9 \)
- Wave load at \( 10^{-4} \) level, daily design conditions \( \eta_{allow} = 0.72 \)

For other special structures such as hatch covers etc. in which direct load assessments are needed, the load and safety factors have to be considered on a case-by-case basis reflecting the actual design lifetime, consequence of failure and the uncertainties in the methods of load and strength assessments in general (e.g. green water on decks etc.).

3.4.1.5 Buckling assessments using recognized FE tools or equivalent are acceptable under the constraints of the following design/modelling principles:

i) The buckling load \( N_B \) is never to exceed the elastic buckling load \( N_E \). This implies that stress-redistributions due to elastic buckling are not accepted, i.e. \( N_B \leq N_E \).

ii) Major plastic yielding of the steel plates is not acceptable. The load at which membrane material yield (von Mises) starts in the face plates gives an acceptable estimate of the buckling load \( N_B \).

iii) The meshing and/or discretization shall be sufficiently fine for realistic stress and deflection assessments. Both shell and solid elements can be used.

iv) The geometrical imperfections in the form of out-of flatness from production have to be considered. A model imperfection in the form of the lowest eigenmode is acceptable.

v) Realistic boundary supports need special considerations.

vi) The buckling criterion under combined in-plane bi-axial and shear loads is

\[
\sqrt{(N_{10})^2 + (N_{20})^2 + (N_{30})^2} < \eta_{allow} \sqrt{(N_{1B})^2 + (N_{2B})^2 + (N_{3B})^2}
\]
or equivalent on compact usage factor format

\[ \eta < \eta_{\text{allow}} \]

where \( \eta_{\text{allow}} \) is the allowable usage factor taken as

\[ \eta_{\text{allow}} = 0.90 \]

and the actual usage is defined as

\[ \eta = \frac{\sqrt{(N_{10})^2 + (N_{20})^2 + (N_{30})^2}}{\sqrt{(N_{1B})^2 + (N_{2B})^2 + (N_{3B})^2}} = \frac{1}{\lambda_B} \]

See 3.4.1.4 for valid accept levels in general.

vii) Instead of a non-linear FE analysis a simplified assessment of the buckling load factor \( \Lambda_B \) follows from

\[ \Lambda_B = \frac{\Lambda_E}{\sqrt{1 + \lambda^4}} \]

\[ \lambda = \frac{\Lambda_F}{\Lambda_E} \]

where \( \Lambda_E \) is the load factor at which elastic buckling starts (eigenvalue).

The \( \Lambda_E \) is the value of the load factor at which the steel face plate reaches the material yield excluding all buckling effects (von Mises squash yield), i.e.

\[ \Lambda_E = \frac{\sigma_{F,\text{steel}}}{\sqrt{\sigma_{10}^2 + \sigma_{20}^2 - \sigma_{10}\sigma_{20} + 3\tau_0^2}} \]

By using this approach non-linear FE analyses are avoided, i.e. only a standard eigenvalue analysis are needed to give an accurate assessment of \( \Lambda_E \) under the actual load combination and boundary conditions.

3.4.1.6 A steel sandwich panel subjected to a set of simultaneously acting design loads in the axial \( (N_{10}) \), transverse \( (N_{20}) \) and in-plane shear \( (N_{30}) \) direction shall satisfy the following buckling criterion

\[ \sqrt{(N_{10})^2 + (N_{20})^2 + (N_{30})^3} < \eta_{\text{allow}} \sqrt{(N_{1B})^2 + (N_{2B})^2 + (N_{3B})^2} \]

expressed more compactly as

\[ \eta < \eta_{\text{allow}} \]

where \( \eta_{\text{allow}} \) is the allowable usage factor taken as

\[ \eta_{\text{allow}} = 0.90 \] (see 3.4.1.4)

and \( \eta \) is the actual usage factor calculated as

\[ \eta = \frac{1}{\Lambda_B} \]

\[ \Lambda_B = \frac{\Lambda_F}{\sqrt{1 + \lambda^4}} \]

\[ \lambda = \frac{\Lambda_F}{\Lambda_E} \]

The corresponding buckling loads are found from

\[ N_{1B} = \Lambda_B N_{10} \]
\[ N_{2B} = \Lambda_B N_{20} \]
\[ N_{3B} = \Lambda_B N_{30} \]

\( \Lambda_F \) is the load factor at squash yielding for the steel face plates found as

---

DET NORSKE VERITAS AS
If
\[ \Lambda_F \leq 1 \]
the pure squash yield criterion is exceeded (neglecting all buckling effects) and the steel sandwich panels cannot carry the applied design loads, \( N_{10}, N_{20}, N_{30} \).

The eigenvalue \( \Lambda_E \) is dependent on the ratio between the design loads. Acceptable closed formed solutions are given next for different load combinations.

3.4.1.7 For panels subjected to bi-axial compression or compression/tension combinations (any \( N_{10}, N_{20} \) combination), the eigenvalue \( \Lambda_E \) can be taken as, i.e.
\[ \Lambda_E = \Lambda_{E,bi} \]

where
\[ \Lambda_{E,bi} = \frac{D_{SFS} \left( \frac{m\pi}{L_1} \right)^2 + \frac{n\pi}{L_2} \right)^2}{1 + \frac{D_{SFS}}{S} \left( \frac{m\pi}{L_1} \right)^2 + \frac{n\pi}{L_2} \right)^2 \left( \frac{m\pi}{L_1} \right)^2 + \frac{n\pi}{L_2} \right)^2} \]

The minimum is to be used (minimization with respect to \( m = 1, 2, 3, \ldots \); \( n = 1, 2, 3, \ldots \))

The eigenvalue component loads under bi-axial loading are accordingly
\[ N_{1E} = \Lambda_{E} N_{10} \]
\[ N_{2E} = \Lambda_{E} N_{20} \]

The single loading cases are readily found by setting the other load component equal to zero.

**Note:**
A negative eigenvalue \( \Lambda_{E,bi} \) means that buckling will not take place for the present load combination. Then set \( \Lambda_B = \Lambda_F \) and \( \eta = 1/\Lambda_F \). If \( 0 < \Lambda_{E,bi} < 1 \) then elastic buckling occurs for acting design loads (i.e. not acceptable).

3.4.1.8 For panels subjected to a single in-plane shear load \( N_{30} \) the eigenvalue can be taken as
\[ \Lambda_E = \frac{N_{3E}}{N_{30}} \]

where the shear buckling load is
\[ N_{3E} = K \frac{\pi^2 D_{SFS}}{L_2^2} \]

where valid for \( L_1 > L_2 \)
\[ K = \frac{K_0}{1 + \pi^2 \theta (K_0 - 1 - (L_2 / L_1)^2} \]

for (simply-supported edges)
\[ K_0 = \frac{16}{3} + 4 \left( \frac{L_2}{L_1} \right)^2 \]

for (simply-supported edges)
3.4.1.9 For panels subjected to bi-axial and in-plane shear loading in combination, the eigenvalue $\Lambda_E$ can be taken as, i.e.

$$\Lambda_E = \Lambda_{E,bi+\tau}$$

where

$$\Lambda_{E,bi+\tau} = \frac{1}{2} \left( \frac{N_{30}}{N_{3E}} \right)^2 \left[ - \frac{1}{\Lambda_{E,bi}} + \sqrt{\left( \frac{1}{\Lambda_{E,bi}} \right)^2 + 4 \left( \frac{N_{30}}{N_{3E}} \right)^2} \right] ; \text{valid for } \Lambda_{E,bi} > 1 N_{30} \neq 0$$

Note:
A negative eigenvalue $\Lambda_{E,bi}$ from 3.4.1.7 means that buckling will not take place for the present bi-axial load combination, i.e. typically the case for tension loads. However, with a simultaneously acting in-plane shear load $N_{30}$ buckling may take place. Thus in the formula for $\Lambda_{E,bi+\tau}$ the actual value for $\Lambda_{E,bi}$ is used from 3.4.1.7, i.e. positive or negative depending on the sign of the bi-axial loads $N_{10}$ and $N_{20}$.
A negative eigenvalue $\Lambda_{E,bi+\tau}$ means that buckling will not take place for the actual load combination $N_{10}$, $N_{20}$, $N_{30}$. Then set $\Lambda_B = \Lambda_E$ and $\eta = 1/\Lambda_E$. If $0 < \Lambda_{E,bi+\tau} < 1$ then elastic buckling occurs for acting design loads (i.e. not acceptable).

---e-n-d---of---N-o-t-e---

3.4.1.10 More accurate assessments of the eigenvalue under combined loads and in-plane shear can be based on numerical solutions using semi-analytical methods or on recognized FE software programs or equivalent.

3.4.1.11 The directly evaluated eigenvalue $\Lambda_E$ then found is knocked down, due to plasticity and out-of flatness imperfections, according to the procedure in 3.4.1.5 vii). The buckling parameter $\Lambda_B$, buckling loads $N_{1B}$, $N_{2B}$ and $N_{3B}$ and usage factor are then evaluated.

3.5 Lateral pressure

3.5.1 Principles

3.5.1.1 A steel sandwich panel subjected to local lateral pressure is to follow elastic design principles so as to avoid major plastic yielding of steel face plating and for limiting too high shear stresses in the core.

3.5.1.2 In addition failure of the bond between the core and the interface shall be avoided as well as failure in the core material itself.

3.5.2 Criteria

3.5.2.1 The assessment of design stresses can be based on linear FE analyses or equivalent methods (semi-analytical) for simulating realistic boundary support etc.

When using FE models the meshing shall be sufficiently fine for realistic stress and deflection assessments. Both shell and solid elements can be used.

3.5.2.2 The local pressures are normally to be based on extreme values relevant for the design lifetime of the structural configuration. The design lifetime correspond to 20 years ($10^{-8}$) in North Atlantic conditions if otherwise not specified.

If Rule design pressures are used ($10^{-4}$) the acceptable surface stress limit are set to be 20% less than for extreme design lifetime pressures ($10^{-8}$).

3.5.2.3 In the lack of detailed FE analyses normally preferred for complex cases with load and pressure variations over the sandwich plating and supporting structure, a simplified analytical assessment based on a simply supported plate model and uniform lateral pressure is acceptable. The stress control in steel face plate, the core and interface/bonding follows the procedures given in 3.5.2.3, 3.5.2.5 and 3.5.2.7 respectively.

The maximum equivalent stress in the steel face plate is to be limited by the following usage factor (stress criterion)

$$\eta \leq \eta_{allow}$$

where

$$\eta = \frac{\sigma_r}{\sigma_{F,steel}}$$

The dimensioning loads are generally to be based on extreme loads relevant for the design lifetime loads ($10^{-8}$).
If the design stresses are taken at $10^{-4}$ level, the acceptable design limit is set to be 20% less than for extreme design lifetime loads ($10^{-8}$).

For redundant structures for which the consequence of failure of the sandwich panel is small the following allowable usage factors apply:

- Wave load at $10^{-8}$ level, 20 year design conditions $\eta_{allow} = 0.9$
- Wave load at $10^{-4}$ level, daily design conditions $\eta_{allow} = 0.72$

For other special structures such as hatch covers etc., the load and safety factors have to be considered on a case-by-case basis reflecting the actual design lifetime, consequence of failure and the uncertainties in the methods of load and strength assessments in general (e.g. green water on decks etc.).

The equivalent von Mises stress is given by

$$\sigma_e = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2 + 3\tau^2}$$

The maximum equivalent stress is to be checked across the whole plate surface and the maximum stress point is to be identified.

The stress components in the steel face plates are

$$\sigma_{1, plate} = M_1 \frac{E_f}{D_{SPS} (1 - \nu_{SPS}^2)} \frac{t_{SPS}}{2}$$

$$\sigma_{2, plate} = M_2 \frac{E_f}{D_{SPS} (1 - \nu_{SPS}^2)} \frac{t_{SPS}}{2}$$

$$\tau_{12, plate} = 2M_{12} \frac{G_f}{D_{SPS} (1 - \nu_{SPS}^2)} \frac{t_{SPS}}{2}$$

The bending moments are found from

$$M_1 = D_{SPS} (w_{h,11} + \nu_{SPS} w_{h,22})$$

$$M_2 = D_{SPS} (w_{h,22} + \nu_{SPS} w_{h,11})$$

$$M_{12} = D_{SPS} (1 - \nu_{SPS})w_{h,12}$$

The lateral plate deflection at any co-ordinate set ($x_1, x_2$) is

$$w = w_b + w_s$$

where

$$w = \sum_{m=1,3,5} \sum_{n=1,3,5} \frac{16}{\pi^2 D_{SPS}} p \int \frac{\left[ \frac{D_{SPS}}{S} \left[ \frac{m\pi}{L_1} \right]^2 + \left[ \frac{n\pi}{L_2} \right]^2 \right] \sin \frac{m\pi x_1}{L_1} \sin \frac{n\pi x_2}{L_2}}{\left[ \left( \frac{m\pi}{L_1} \right)^2 + \left( \frac{n\pi}{L_2} \right)^2 \right]^2} mn$$

with bending component

$$w_b = \sum_{m=1,3,5} \sum_{n=1,3,5} \frac{16}{\pi^2 D_{SPS}} p \int \frac{\left[ \frac{D_{SPS}}{S} \left[ \frac{m\pi}{L_1} \right]^2 + \left[ \frac{n\pi}{L_2} \right]^2 \right] \sin \frac{m\pi x_1}{L_1} \sin \frac{n\pi x_2}{L_2}}{\left[ \left( \frac{m\pi}{L_1} \right)^2 + \left( \frac{n\pi}{L_2} \right)^2 \right]^2} mn$$
and shear component

\[ w_j = \frac{16}{\pi^2 D_{SFS}} p \sum_{m=1.5}^{3} \sum_{n=1.5}^{3.5} \left[ \frac{D_{SFS}}{S} \left( \frac{m\pi}{L_1} + \frac{n\pi}{L_2} \right)^2 \sin \frac{m\pi}{L_1} \sin \frac{n\pi}{L_2} \right] \left[ \frac{m\pi}{L_1} + \frac{n\pi}{L_2} \right]^{2mn} \]

The derivatives \( w_{b,11}, w_{b,22}, w_{b,12} \) are given in the notation list.

3.5.2.4 The relative out-of-plane deflection of panels should be checked against possible limits imposed by functional requirements.

**Note:**
The maximum deflection should typically not be greater than few per cent of \( L_2 \) (shortest plate length) unless otherwise stated in the Rule or agreed with the Society. For panels exposed to long term static loads the maximum deflection should be reduced to 1%.

---e-n-d---of---N-o-t-e---

3.5.2.5 The core shear stress is to be limited by

\[ \eta \leq \eta_{allow} \]

where

\[ \eta = \frac{\tau_{core}}{\tau_{allow,core}} \]

and

\( \eta_{allow} = 0.9 \) for load at 10\(^{-8}\) probability level, direct assessments

\( \eta_{allow} = 0.72 \) for load at 10\(^{-4}\) probability level, Rules loads

For other special structures such as hatch covers etc., the load and safety factors have to be considered on a case-by-case basis reflecting the actual design lifetime, consequence of failure and the uncertainties in the methods of load and strength assessments in general (e.g. green water on decks etc.).

The core shear stress is the maximum of

\[ \tau_{13,core} = \frac{S}{d} w_{s,1} \]

\[ \tau_{23,core} = \frac{S}{d} w_{s,2} \]

The derivatives \( w_{s,1}, w_{s,2} \) are given in the notation list.

3.5.2.6 The allowable core shear stress is to not be less than

\[ \tau_{allow,core} = \frac{\tau_{yield,core}}{\gamma_{m,core}} \]

where the core partial safety factor \( \gamma_{m,core} = 1 \) as default but is to be agreed with the Society on a case-by-case basis, see 3.5.2.3.

When the yield stress in shear of elastomer core is not available the allowable core shear stress shall be calculated by the expression given below

\[ \tau_{allow,core} = \frac{\sigma_{yield,core}}{\gamma_{m,core}\sqrt{3}} \]

For SPS elastomer core \( \sigma_{yield,core} \) should be taken as 21 MPa, i.e the allowable shear stress is

\[ \tau_{allow, core} = 12 \, MPa \]
3.5.2.7 The maximum interface shear stress shall be lower than the allowable bond shear stress such that

$$\eta \leq \eta_{allow}$$

where

$$\eta = \frac{\tau_{bond}}{\tau_{allow.bond}}$$

and

$$\eta_{allow} = 0.9$$ for load at $10^{-8}$ probability level, direct assessments

$$\eta_{allow} = 0.72$$ for load at $10^{-4}$ probability level, Rules loads

For other special structures such as hatch covers etc., the load and safety factors have to be considered on a case-by-case basis reflecting the actual design lifetime, consequence of failure and the uncertainties in the methods of load and strength assessments in general (e.g. green water on decks etc.).

3.5.2.8 The maximum interface shear stress is to be calculated using direct design calculations for all load conditions unless otherwise specified. For hydrostatic pressure acting on a simply supported plate, the maximum interface shear stress for Sandwich Plate Systems, is to be taken as

$$\tau_{bond} = \left[ 0.1 \left( \frac{L_1}{L_2} \right) + 0.65 \right] \mu L_2 \kappa$$

where $\kappa$ is a parameter given in Table 3-5.

| Table 3-5 Value of $\kappa$-parameter in function of panel aspect ratio |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $L_1/L_2$ | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | $\infty$ |
| $\kappa$ | 0.44 | 0.49 | 0.52 | 0.52 | 0.52 | 0.50 |

3.5.2.9 For Sandwich Plate Systems, the allowable bond shear stress shall be determined by

$$\frac{1}{\phi_t \phi_s} \left[ \frac{\sigma_n}{8.6} + \frac{\tau_{ult,bond}}{13.5} \right] \leq 1.0$$

and

$$\tau_{allow.core} = \frac{\tau_{ult,bond}}{\gamma_{m,bond}}$$

where $\sigma_n$ are the normal stress perpendicular to the interface and $\tau_{ult,bond}$ is the ultimate shear stresses across the interface between steel face plates and the core taken at the same point at any location within the sandwich panel for a given load condition.

The parameters $\phi_t$ and $\phi_s$ are modification factors for varying temperature conditions and surface preparation, and are listed in Table 3-6 and Table 3-7.

3.5.2.10 $\gamma_{m,bond}$ is the bond partial safety factor. The bond partial safety factor of 1.8 should be used as default but is to be agreed with the Society on a case-by-case basis.

A normal stress of zero can be used for sandwich plates under lateral pressure only. In such case, then for steel grit-blasted surfaces at 20°C (i.e. $\phi_t = \phi_s = 1.00$) it follows $\tau_{ult,bond} = 13.5$ MPa and $\tau_{allow.bond} = 7.5$ MPa

| Table 3-6 Modification factor for temperature, $\phi_t$ |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Temperature, C | -40 | -20 | 0 | 20 | 40 | 60 | 80 | 100 |
| 1.31 | 1.28 | 1.21 | 1.00 | 0.71 | 0.48 | 0.33 | 0.19 |

| Table 3-7 Modification factor for surface preparation, $\phi_s$ |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|
| Surface Preparation | Mechanical Grinding | Grit Blast | Shot Blast | Primer |
| | 1.15 | 1.00 | 0.70 | 0.40 |
4. Strength Overlay Construction

4.1 General

4.1.1 Introduction

4.1.1.1 The requirements in this section apply to overlay steel sandwich panel used in repair or reinforcement of existing steel construction of shell, bulkheads and deck structures.

4.1.2 Steel grade

4.1.2.1 In general, the steel grade of the top plate is to match the steel grade of the existing structure. Justification for use of a different steel grade is to be included as part of the submitted design documentation.

4.1.3 Minimum thickness

4.1.3.1 Minimum thickness of overlay construction is given in Table 4-1.

<table>
<thead>
<tr>
<th>Table 4-1 Minimum thickness in mm for overlay construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1 \text{ min}$</td>
</tr>
<tr>
<td>$t_2 \text{ min}$</td>
</tr>
<tr>
<td>$t_\text{ core}$</td>
</tr>
</tbody>
</table>

4.1.4 Corrosion

4.1.4.1 Bottom plate corrosion shall not be corroded over the percentage values given in Table 4-2.

4.1.4.2 Stiffening and girder system shall be intact or repaired according to the Rules criteria.

<table>
<thead>
<tr>
<th>Table 4-2 Allowable corrosion percentage before application of overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>doublers plates acceptable for category B only</td>
</tr>
<tr>
<td>insert plates</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4-3 Corrosion allowance, $t_k$ (mm) for new top plating and allowable further corrosion allowance for existing plate subsequent to application of overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural member</td>
</tr>
<tr>
<td>Upper Deck Panel (weather deck)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Inner Bottom and Hopper tank Panel in cargo area</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Inner Bottom outside cargo area</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Inner Decks and Ramps</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Other panels</td>
</tr>
</tbody>
</table>

1) When heated cargo tank
2) Further allowance may be considered based on strength calculation in each case.
4.2 Scantlings

4.2.1 Effective section moduli of sandwich plates with stiffeners

4.2.1.1 In cases where a sandwich plate is designed using the plate of an existing stiffened section, the effective section moduli, $Z_1^{\text{eff}}$ and $Z_2^{\text{eff}}$, shall be greater than the section modulus as provided by the Rules for the given application.

4.2.1.2 The effective section moduli for sandwich plates with stiffeners shall be taken as

$$Z_{1\text{eff}} = Z_1 \alpha_1$$
$$Z_{2\text{eff}} = Z_2 \alpha_2$$

where,

$Z_1$ and $Z_2$ are the section moduli of the sandwich plate with stiffener for the top and bottom extreme fibers respectively, assuming strain compatibility and a linear strain distribution, for the top and bottom of the section, respectively, and expressed in mm$^3$. $\alpha_1$ and $\alpha_2$ are effective section moduli factor.

4.2.1.3 In cases where the stiffener is connected with through-thickness steel to the top face plate then $\alpha_1$ and $\alpha_2$ shall be taken as 1.00.

4.2.1.4 In cases where the stiffener is not connected with through-thickness steel to the top face plate then $\alpha_1$ and $\alpha_2$ shall be taken as

$$\alpha_1 = \frac{1}{\beta_1} \left[ 0.97 + 0.4 \frac{t_s}{r} \right]$$
$$\alpha_2 = \frac{1}{\beta_2} \left[ 0.99 - 30 \frac{t_s}{rl_s} \right]$$

where $\beta_1$ and $\beta_2$ shall be taken as given in Table 4-4.

<table>
<thead>
<tr>
<th>Stiffener type</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulb Flat</td>
<td>1.07</td>
<td>1.02</td>
</tr>
<tr>
<td>Angle</td>
<td>$1.32 - 0.0034 \frac{t_s}{s}$</td>
<td>$1.093 - 0.0045 \left( \frac{b_s h_s}{t_s t_f l_s} \right)$</td>
</tr>
<tr>
<td>Tee</td>
<td>1.054</td>
<td>1.005 - 1.3 $\frac{t_s}{h_s}$</td>
</tr>
</tbody>
</table>

5. Connections

5.1 General

5.1.1 General requirements

5.1.1.1 The requirements and recommendations given in this section apply to connections used in assembly of new sandwich construction and overlay sandwich construction.

5.1.1.2 The connection details shall be arranged to ensure reliable and effective load transfer to the adjacent structure.

5.1.1.3 Attention is drawn to the importance of structural continuity. Structural continuity shall be maintained at the junction of structural members and panels of unequal stiffness. The transitions shall be smooth and without local discontinuities. Proper alignment of the different structural members shall be achieved.

5.1.1.4 When two sandwich structures are joined complicated stress fields may result inside the sandwich structure. Stresses inside the core can be very different near a joint compared to the typical shear stresses in a panel.
5.1.1.5 Connections may be designed according to three different approaches:

- An analytical approach, i.e. the stress/strain levels at all relevant parts of the connections including the interface are determined by means of a stress analyses (e.g. a FE analysis) and compared with the relevant data on the mechanical strength.
- Design by qualification testing only, i.e. full scale or scaled down samples of the joint are tested under relevant conditions such that the characteristic strength of the complete joint can be determined.
- A combination of an analytical approach and testing.

5.2 Newbuilding

5.2.1 Connections

5.2.1.1 Connections may be accepted provided it can be demonstrated that a satisfactory structural performance is achieved. A selection of typical connection details are shown in Table 5-1. Weld groove preparations are to be specified in the documentation. Excessive welds should be avoided.

Table 5-1 Connections details for new construction

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter bar - deck and sloping bulkhead connection</td>
<td></td>
</tr>
<tr>
<td>Perimeter bar - deck shell and bulkhead connection</td>
<td></td>
</tr>
</tbody>
</table>

Perimeter bar - deck and sloping bulkhead connection

Perimeter bar - deck shell and bulkhead connection
5.3 Overlay

5.3.1 Typical connections

5.3.1.1 A variety of typical, proven connection details have been developed to join the panels (prefabricated or not) together to the conventional ship structure. These are shown in Table 5-2. The selection of details and variants will depend on stress levels and arrangement of existing structures.

5.3.2 Alternative connections

5.3.2.1 Alternative connections may be accepted provided it can be demonstrated that the satisfactory structural performance is achieved.

<table>
<thead>
<tr>
<th>Table 5-2 Connections details for overlay construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram of standard detail for adjacent panels]</td>
</tr>
<tr>
<td>![Diagram of different terminations at horizontal deck]</td>
</tr>
</tbody>
</table>

Standard detail for adjacent panels

Alternative for termination at bulkhead

Different terminations at horizontal deck

Perimeter bar connections
### 6. Fire Safety

#### 6.1 General

**6.1.1 Applicable rules**

6.1.1.1 The requirements given in this section apply to steel sandwich construction and shall be regarded as supplementary to those given in Pt.4 Ch.10 of the Rules.

**6.1.2 SOLAS safety certificates**

6.1.2.1 See Pt.4 Ch.10 Sec.1 B200.

#### 6.2 Newbuilding

**6.2.1 Classification**

6.2.1.1 Where the government of the flag state has authorised the Society to issue the SOLAS safety certificates on its behalf, the Society will give effect to the alternative design requirements of Ch.II-2 Reg.17 of SOLAS. The methodology for engineering analysis defined in the guidelines of IMO MSC/Circ.1002 should then be used to demonstrate and document fire safety equivalence for newbuilding construction.

6.2.1.2 Alternatively, where the government of the flag state has not authorised the Society to issue the SOLAS safety certificates on its behalf, the same methodology may be used to demonstrate and document fire safety equivalence, at the discretion of the flag state.

#### 6.3 Overlay

**6.3.1 Preamble**

6.3.1.1 The fire resistance and fire reaction properties of steel elastomer sandwich panel construction are

---

**Table 5-2 Connections details for overlay construction (Continued)**

<table>
<thead>
<tr>
<th>Termination at bulkhead stool</th>
<th>Hopper knuckle detail</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Termination at bulkhead stool" /></td>
<td><img src="image2" alt="Hopper knuckle detail" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hopper knuckle detail</th>
<th>Connection to structure inside stool tank, vertical bhd. and similar</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Hopper knuckle detail" /></td>
<td><img src="image4" alt="Connection to structure inside stool tank, vertical bhd. and similar" /></td>
</tr>
</tbody>
</table>
deemed to be equivalent to a conventional steel structure.

6.3.2 Classification
6.3.2.1 Steel sandwich overlay shall be in compliance with Pt.4 Ch.10.

7. Direct Strength Calculations
7.1 Introduction
7.1.1 General
7.1.1.1 The Section specifies requirements and recommendations for direct strength analysis of steel sandwich construction with emphasis on Finite Element Method (FEM) of steel sandwich construction for specific loads, environments and boundary conditions.
7.1.1.2 The requirements shall be regarded as supplementary to those given in Pt.3 Ch.1 Sec.12 and Pt.5 of the Rules.
7.1.1.3 It is of primary importance to the analysis of steel sandwich panel construction to assess structural behaviour and structural strength and stiffness, i.e.

— yield strength of the faces
— the shear strength of the core
— the bond strength of the interface
— the deflection.

7.1.1.4 The local response of the steel sandwich structure can in principle be analysed at the following different material levels:

— the “constituent/material level” or “ply level” corresponding to the plate and core, separately
— the “laminate level” corresponding to the whole sandwich structure.

7.1.1.5 The response of steel sandwich structure should however be analysed at a material level consistent with the failure criteria used in the analysis.

7.2 Modelling
7.2.1 Material models and properties
7.2.1.1 For steel sandwich structures the core and faces materials are isotropic and can be described by two elastic constants.

7.2.1.2 For many core materials, experimentally measured values of $E_c$, $G_c$ and $\nu_c$ are not in agreement with the isotropic formula:

$$G_c = \frac{E_c}{2(1+\nu_c)}$$

If the elements applied in the FE analysis do not allow values for all three parameters to be specified, one should generally use the measured values for $G_c$ and $\nu_c$, and let the $E_c$ value be calculated by the program. In that case the shear response of the core will be described accurately.

7.2.2 Element types
7.2.2.1 In the context of FE analysis of steel sandwich structures one of the following element types or combinations should be applied:

— a single layer of layered shell elements through the thickness of the entire sandwich material with isotropic material properties for each layer
— (layered) shell elements for the faces and solid elements for the core with isotropic material properties for both element types. In this case compensation may be desirable for the change in stiffness, or alternatively, in order to avoid overlapping areas, shell elements can be positioned adequately without the need for modifying the material properties by using the eccentricity property of the element. Depending on the commercial package used, this option is not always available.
— solid elements for both faces and core with isotropic material properties.
7.2.2.2 For the analysis of sandwich structures, special considerations should be taken into account, such as:
— elements including core shear deformation shall be selected
— local load introductions, corners and joints, should be checked
— curved panels with small radii of curvature should be analysed in 2-D (through thickness direction) or 3-D to account for the transverse normal stresses not included in shell elements.

7.2.2.3 By the use of solid elements the correct geometry can be modelled to the degree of detail wanted. However, this may imply that the model will include a very large number of nodes and elements, and hence the solution time will be very long. Furthermore, as most solid element types only have three degrees of freedom at each node, the mesh for a solid model may need to be denser than for a beam or shell element model.

7.2.3 Combinations

7.2.3.1 The following guideline can be used for the element selection and distribution for the design of a ship component made of steel sandwich panels:
— Face plates can be modelled using shell elements with isotropic material properties.
— Core material can be modelled using solid elements with isotropic material properties.
— Girders and stiffeners can be modelled using beam elements and/or shell elements.

Note:
For panels with rotationally clamped edges the maximum stresses occur at the plate boundaries. (Here, the effects of local bending of the faces sheets influence the stresses, and these effects can only be included by using higher order theory that couples the shear and the bending solution). The use of a single layer of thick shell elements cannot be used to predict accurately these stresses and a model with multiple layers of solid elements, or shell elements combined with solid elements, should be used.
However, local bending stresses in the plating at supports can be neglected provided it can be demonstrated that these will not cause fatigue problems for the case under consideration.

7.3 References
Appendix A
Symbols and Notations

A.1 Basic construction and materials notations

\[ \begin{align*}
  t_1 & = \text{thickness of upper steel face plate, i.e. top plate} \\
  t_2 & = \text{thickness of lower steel face plate, i.e. lower plate} \\
  t_c & = \text{thickness of core} \\
  t_k & = \text{corrosion allowance} \\
  t_{SPS} & = \text{thickness of the steel sandwich panel, } t_{SPS} = t_1 + t_2 + t_c \\
  w & = \text{lateral deflection of plate, } w = f(x_1, x_2) \\
  d & = \text{thickness parameter, } d = t_c + (t_1 + t_2)/2 \\
  \phi_s & = \text{surface preparation modification factor} \\
  \phi_t & = \text{temperature modification factor} \\
  \sigma_{F, \text{steel}} & = \text{nominal yield stress of steel plates} \\
  \sigma_{\text{yield,core}} & = \text{yield stress in tension of elastomer core, characteristic value} \\
  \tau_{\text{yield,core}} & = \text{yield stress in shear of elastomer core, characteristic value} \\
  \tau_{\text{ultimate bond}} & = \text{ultimate bond strength, characteristic value} \\
  \tau_{\text{allow,core}} & = \text{allowable shear stress of elastomer core} \\
  \tau_{\text{allow, bond}} & = \text{allowable bond shear stress} \\
  \gamma_{m, \text{core}} & = \text{core safety factor, } \gamma_{m, \text{core}} = 1.0 \text{ as default, value to be approved by the Society} \\
  \gamma_{m, \text{bond}} & = \text{bond safety factor, } \gamma_{m, \text{bond}} = 1.8 \text{ as default, value to be approved by the Society} \\
  E_c & = \text{Young’s modulus of core material} \\
  E_f & = \text{Young’s modulus of steel face plates} \\
  \nu_c & = \text{Poisson ratio of core material e.g. polyurethane} \\
  \nu_s & = \text{Poisson ratio of steel face plates} \\
  \nu_{SPS} & = \text{Poisson ratio of SPS plate, see A.2 below} \\
  G_c & = \text{shear modulus of core material, where } G_c = \frac{E_c}{2(1 + \nu_c)} \\
  \beta_1 \text{ and } \beta_2 & = \text{stiffener type factor, defined in Table 4-4} \\
  r & = \text{span of the stiffener in mm} \\
  l_s & = \text{span of the stiffener in mm} \\
  s & = \text{stiffener spacing in mm} \\
  h_s & = \text{depth of the stiffener in mm} \\
  t_w & = \text{web thickness in mm} \\
  b_f & = \text{flange width in mm} \\
  t_f & = \text{flange thickness in mm} \\
  p & = \text{uniform lateral pressure on plating} \\
  z_1 & = \text{effective section modulus for the top extreme fibres} \\
  z_2 & = \text{effective section modulus for the bottom extreme fibres.}
\end{align*} \]

A.2 Special notations and formulas

**SPS general stiffness parameters**

\[ D_{SPS} = \frac{E_c t_c^3}{12(1 - \nu_c^2)} + \frac{E_f}{4(1 - \nu_f^2)} \left[ t_2 (t_c + t_2)^2 + t_1 (t_c + t_1)^2 \right] \]

\[ V_{SPS} = \frac{\nu_c E_c t_c (1 - \nu_f^2) + \nu_f E_f (t_1 + t_2)(1 - \nu_c^2)}{E_c t_c (1 - \nu_f^2) + E_f (t_1 + t_2)(1 - \nu_c^2)} \]

\[ C_{SPS} = \frac{E_c t_c}{(1 - \nu_c^2)} + \frac{E_f}{(1 - \nu_f^2)} (t_1 + t_2) \]
\[ S = \frac{G_i d^2}{t_c} \]
\[ \theta = \frac{D_{ses}}{L_2^2 S} ; \; L_1 > L_2 \]

**Buckling**

\[ \Lambda = \text{proportional load factor with respect to design loads defined as (see Fig. A-1)} \]

\[ N_1 = \Lambda N_{10} \]
\[ N_2 = \Lambda N_{20} \quad (\text{i.e. } \Lambda = 1 \text{ for design in-plane loads; } N_{10}, N_{20}, N_{30}) \]
\[ N_3 = \Lambda N_{30} \]

where,
\[ N_{10} = \text{design axial line load including relevant load factors (N/mm; acting perpendicular to the shortest plate edge; > 0 compression)} \]
\[ N_{20} = \text{design transverse line load including relevant load factors (N/mm; acting perpendicular to the longest plate edge; > 0 compression)} \]
\[ N_{30} = \text{design in-plane shear load including relevant load factors, per unit length (N/mm).} \]

For loads at elasto-plastic buckling of plating (ref. buckling parameter \( \Lambda_B \))

\[ N_{1B} = \Lambda_B N_{10} \]
\[ N_{2B} = \Lambda_B N_{20} \]
\[ N_{3B} = \Lambda_B N_{30} \]

For loads at elastic buckling of plating (ref. eigenvalue parameter \( \Lambda_E \))

\[ N_{1E} = \Lambda_E N_{10} \]
\[ N_{2E} = \Lambda_E N_{20} \]
\[ N_{3E} = \Lambda_E N_{30} \]

Actual usage factor \( \eta \) is defined as

\[ \eta = \frac{\sqrt{(N_{10})^2 + (N_{30})^2 + (N_{30})^2}}{\sqrt{(N_{1B})^2 + (N_{2B})^2 + (N_{3B})^2}} = \frac{1}{\Lambda_B} \]

\( \Lambda_B \) = load factor at buckling corrected with respect to elasto-plastic material effects of steel face plates
(\( \Lambda_B \) is the safety factor against buckling = inverse of usage factor)

\( \Lambda_E \) = load factor at elastic buckling (ref. eigenvalue)

\( \Lambda_F \) = load factor at squash material yielding of steel face plates (neglecting all buckling effects)

\( \sigma_F \) = yield stress of steel face plates

\( \sigma_{10} \) = design axial stress in steel face plate

\( \sigma_{20} \) = design transverse stress in steel face plate

\( \sigma_{30} \) = design in-plane shear stress in steel face plate

\( p \) = uniform lateral pressure on plating

\( L_1 \) = axial length of panel, span between frames, \( L_1 > L_2 \) always in present formulas

\( L_2 \) = transverse length of panel, span between frames etc.

\( m \) = half waves in buckling pattern, axial direction (\( \ell_f = L_1/m \))

\( n \) = half waves in buckling pattern, transverse direction (\( \ell_2 = L_2/n \))
Figure A-1
Design loads, buckling load and usage factor schematically illustrated

Lateral pressure

Face direct stress parameters are given by:

\[ W_{b,11} = \frac{16}{\pi^2 D_{SPS}} p \sum_{m=1,3,5} \sum_{n=1,3,5} (\frac{m\pi}{L_1})^2 \left( \frac{m\pi}{L_2} \right) \sin \left( \frac{n\pi}{L_1} \right) \sin \left( \frac{n\pi}{L_2} \right) \]

\[ W_{b,22} = \frac{16}{\pi^2 D_{SPS}} p \sum_{m=1,3,5} \sum_{n=1,3,5} (\frac{n\pi}{L_1})^2 \left( \frac{n\pi}{L_2} \right) \sin \left( \frac{m\pi}{L_1} \right) \sin \left( \frac{m\pi}{L_2} \right) \]

Core shear stress parameters are defined as:

\[ W_{v,1} = \frac{16}{\pi^2 D_{SPS}} p \sum_{m=1,3,5} \sum_{n=1,3,5} \left( \frac{m\pi}{L_1} \right) \left( \frac{m\pi}{L_2} \right) \cos \left( \frac{m\pi}{L_1} \right) \cos \left( \frac{m\pi}{L_2} \right) \sin \left( \frac{n\pi}{L_1} \right) sin \left( \frac{n\pi}{L_2} \right) \]

\[ W_{v,2} = \frac{16}{\pi^2 D_{SPS}} p \sum_{m=1,3,5} \sum_{n=1,3,5} \left( \frac{n\pi}{L_1} \right) \left( \frac{n\pi}{L_2} \right) \cos \left( \frac{n\pi}{L_1} \right) \cos \left( \frac{n\pi}{L_2} \right) \sin \left( \frac{m\pi}{L_1} \right) \sin \left( \frac{m\pi}{L_2} \right) \]
Moment-curvatures are defined as

\[ M_1 = \frac{D_1}{1 - v_{12}^2} (w_{b,11} + v_{21} w_{b,22}) \]
\[ M_2 = \frac{D_2}{1 - v_{12}^2} (w_{b,22} + v_{12} w_{b,22}) \]
\[ M_{12} = D_{12} w_{b,12} \]

Shear force – shear strain (through thickness) are given by

\[ Q_1 = S_1 w_{s,1} \]
\[ Q_2 = S_2 w_{s,2} \]

Stiffness coefficients specialized for isotropic steel sandwich plate are defined as

\[ D_1 = D_{SPS}(1 - v_{SPS}^2) = D_{Zenkert} \]
\[ D_2 = D_{SPS}(1 - v_{SPS}^2) = D_{Zenkert} \]
\[ D_{12} = D_{SPS}(1 - v_{SPS}) = D_{Zenkert} \]
\[ V_{12} = V_{21} = V_{SPS} \]
\[ S = S_1 = S_2 \]

The symbol D is normally defined in the literature for an isotropic thin shell of thickness t as (e.g. in Ref. (2) and Ref. (3))

\[ D = \frac{E t^3}{12(1 - \nu^2)} \]

\[ D_{Zenkert} = \frac{E t^3}{12} \]
\[ D = \frac{D_{Zenkert}}{(1 - \nu^2)} \]
\[ \theta = \frac{D_{Zenkert}}{L_2^2 S (1 - v_{SPS}^2)} = \frac{D_{SPS}}{L_2^2 S} ; L_1 > L_2 \]

General orthotropic plate properties

Constitutive relation for symmetric orthotropic material:

\[
\begin{bmatrix}
N_1 \\
N_2 \\
N_3 \\
M_1 \\
M_2 \\
M_3
\end{bmatrix} =
\begin{bmatrix}
C_{11} & C_{12} & 0 & 0 & 0 & 0 \\
C_{21} & C_{22} & 0 & 0 & 0 & 0 \\
0 & 0 & C_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & D_{11} & D_{12} & 0 \\
0 & 0 & D_{21} & D_{22} & 0 & \kappa_2 \\
0 & 0 & 0 & D_{33} & \kappa_3
\end{bmatrix} \begin{bmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\kappa_1 \\
\kappa_2 \\
\kappa_3
\end{bmatrix}
\]

where \( C_{11}, C_{12}, \ldots \) etc. are extensional stiffness coefficients and \( D_{11}, D_{12}, \ldots \) etc. are bending stiffness coefficients.

The extensional anisotropic stiffness coefficients of a steel sandwich plate, \( C_{\alpha\beta} \), are given by
Orthotropic; 4 independent parameters $C_{11}, C_{22}, C_{33}, C_{12} = C_{21}$

$$C_{11} = \frac{E_t t_c}{(1-\nu_c^2)} + \frac{E_f}{(1-\nu_f^2)}(t_1 + t_2)$$

$$C_{12} = \frac{\nu_f E_t t_c}{(1-\nu_c^2)} + \frac{\nu_f E_f}{(1-\nu_f^2)}(t_1 + t_2)$$

$$C_{22} = C_{11}$$

$$C_{33} = \frac{E_t t_c}{2(1+\nu_c)} + \frac{E_f}{2(1+\nu_f)}(t_1 + t_2)$$

$$C_{33} = C_{31} = C_{32} = 0$$

$$\begin{bmatrix} N_1 \\ N_2 \\ N_3 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & 0 \\ C_{21} & C_{22} & 0 \\ 0 & 0 & C_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix}$$

Orthotropic; 4 independent parameters $C_{11}, C_{22}, C_{33}, C_{12} = C_{21}$

$$N_1 = C_{SPS} (\varepsilon_1 + \nu_{SPS} \varepsilon_2)$$

$$N_2 = C_{SPS} (\nu_{SPS} \varepsilon_1 + \varepsilon_2)$$

Isotropic notation; 2 independent parameter, $C_{SPS}, \nu_{SPS}$

$$N_3 = \frac{C_{SPS}}{2} \varepsilon_3$$

$$\begin{align*}
N_1 &= C_{SPS} (\varepsilon_1 + \nu_{SPS} \varepsilon_2) \\
N_2 &= C_{SPS} (\nu_{SPS} \varepsilon_1 + \varepsilon_2) \\
N_3 &= \frac{C_{SPS}}{2} \varepsilon_3
\end{align*}$$

($\varepsilon_1 = 0; \nu_{SPS} = \frac{N_1}{N_2} = \frac{C_{12} \varepsilon_2}{C_{22} \varepsilon_2}$)

In lieu of more accurate coefficients the bending stiffness coefficients $D_{\alpha\beta}$ can be taken as

$$D_{11} = \frac{E_t t_c^3}{12(1-\nu_c^2)} + \frac{E_f}{4(1-\nu_f^2)} \left[ t_2^2 (t_c + t_2)^2 + t_1 (t_c + t_1)^2 \right] = \frac{D_x}{1-\nu_{xy}^2}$$

$$D_{12} = \frac{\nu_f E_t t_c^3}{12(1-\nu_c^2)} + \frac{\nu_f E_f}{4(1-\nu_f^2)} \left[ t_2^2 (t_c + t_2)^2 + t_1 (t_c + t_1)^2 \right] = \frac{\nu_{xy} D_x}{1-\nu_{xy}^2}$$

$$D_{22} = D_{11}$$

$$D_{12} = D_{21}$$

$$D_{33} = \frac{E_t t_c^3}{12(1+\nu_c)} + \frac{E_f}{4(1+\nu_f)} \left[ t_2^2 (t_c + t_2)^2 + t_1 (t_c + t_1)^2 \right] = D_\nu$$

$$D_{13} = D_{31} = D_{23} = D_{32} = 0$$
Moment-curvature relation (linear)

\[
N = C \varepsilon
\]

In-plane load-strain relation (linear)

\[
\varepsilon = FN, F = C^{-1}
\]

Inverse relation (linear)

\[
\varepsilon_1 = \text{axial in-plane strain}
\]

\[
\varepsilon_2 = \text{transverse in-plane strain}
\]

\[
\varepsilon_3 = \text{in-plane shear strain, } \gamma \text{ where } \gamma \text{ is the normal engineering shear strain}
\]

\[
C_{33} = \text{shear stiffness, } C_{33} = 2C_{12} \text{ where } C_{12} \text{ is the coefficient used in some literature}
\]

\[
\kappa_1 = \text{bending curvature in axial direction (about } x_2\text{-axis), } \kappa_1 = w_{b,11}
\]

\[
\kappa_2 = \text{bending curvature in transverse direction (about } x_1\text{-axis), } \kappa_2 = w_{b,22}
\]

\[
\kappa_3 = \text{twisting bending curvature, } \kappa_3 = w_{b,12}; \kappa_3 = (1/2) \kappa_{12} \text{ where } \kappa_{12} \text{ is the engineering bending shear strain}
\]

\[
D_{33} = \text{shear twisting stiffness, } D_{33} = 2D_{66} \text{ where } \kappa_{12} \text{ and } D_{66} \text{ related to notation used in several text books)}
\]

\[
\text{i.e. positive curvatures give compressive strains on concave side of plate.}
\]

Linear material behaviour in steel

\[
\sigma_1 = \frac{E_f}{(1 - \nu_f^2)} (\varepsilon_1 + \nu_f \varepsilon_2)
\]

\[
\sigma_2 = \frac{E_f}{(1 - \nu_f^2)} (\varepsilon_2 + \nu_f \varepsilon_1)
\]

\[
\sigma_3 = \frac{E_f}{2(1 + \nu_f)} \varepsilon_3
\]

Linear material behaviour in core

\[
\sigma_1 = \frac{E_c}{(1 - \nu_c^2)} (\varepsilon_1 + \nu_c \varepsilon_2)
\]

\[
\sigma_2 = \frac{E_c}{(1 - \nu_c^2)} (\varepsilon_2 + \nu_c \varepsilon_1)
\]

\[
\sigma_3 = \frac{E_c}{2(1 + \nu_c)} \varepsilon_3
\]
Appendix B
SSPC Strength Calculator
Click here to download a supporting Excel tool for 3.4 Buckling and 3.5 Lateral Pressure.